Simulation of H1 Networks

by Analog Services, Inc.

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1. Introduction

The H1 topologies permit all of the following:

1. Total cable lengths up to 1900 meter.

2. Drops of relatively long and varying lengths, located anywhere along the trunk.

3. Up to 32 devices per network, each having a relatively low device impedance of 3000 ohm.

4. Mixing of different cables in a given network.

Given this desired degree of latitude in constructing networks, there do not appear to be any simple rules or first-order approximations that can be applied to insure that attenuation and delay distortion are within acceptable limits. It is not satisfactory to simply state the desired attenuation and distortion limits. These are not configuration rules. Rather they are the desired outcome of applying the rules.

To make it easy to build conformant networks, the network configuration rules should consist of limits on drop and trunk lengths. These limits can be based on simulations. To this end, we present this report. Although more work remains to be done, the information provided illustrates what can be achieved.

2. Simulation Description

The simulation assumes that every network consists of the parts shown in figure 1. The trunk is a single homogeneous length of cable, as is each drop. The trunk has a terminator at each end consisting of a resistor and capacitor in series. Each drop has a load at the end opposite the trunk, consisting of a resistor and capacitor in parallel. Each cable segment of figure 1 is modeled as a doubly-loaded transmission line, with each load being the driving point impedance of a combination of other lumped and distributed elements.

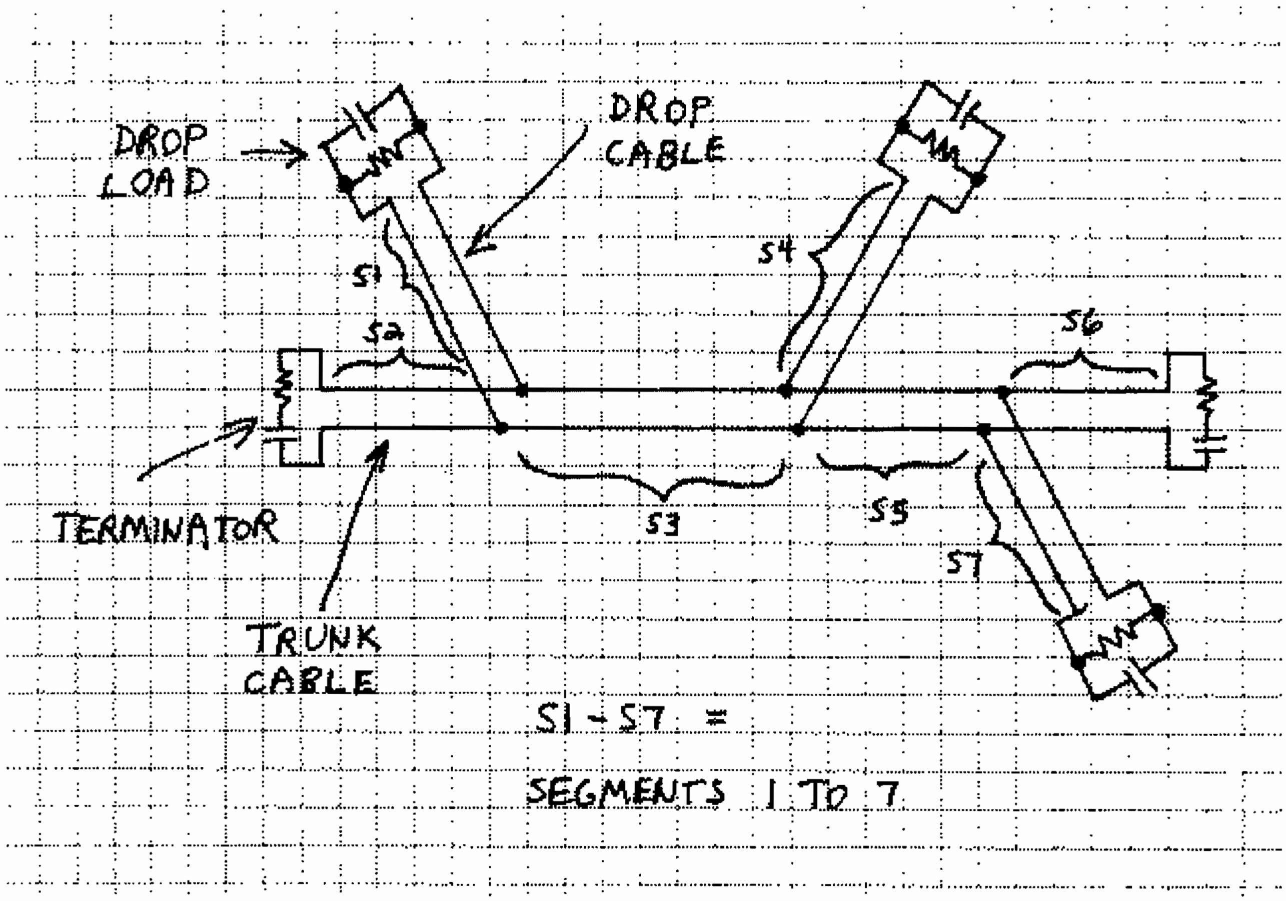


Figure 1 -- Network Model

Although the figure illustrates a BUS network, the simulations can be applied tc the TREE network as well. The TREE is just a special case of the EUS in which all drops are located at one end of the trunk.

The simulation is divided into two stages. In the first stage, a large number of networks are constructed and each is analyzed. The worst transmission path of the worst network is found. In the 2nd stage, a large number of data streams are generated. Each is Manchester encoded and sampled. The samples are transformed to the frequency domain and the result is filtered using the worst case transfer function found in the first stage of simulation. The frequency domain information is transformed back to the time domain. All waveforms are then either plotted or else searched for the worst (smallest) eye opening among all waveforms.

2.1 First Stage Simulation

The first stage of simulation needs a criterion for the worst transmission path of the worst network. There are actually three different criteria that are used. These are

1. Maximum Magnitude Ratio between any two frequencies in the 0.25 Fr to 1.25 Fr band.

2. Maximum Delay Difference between any two frequencies in the 0.25 Fr to 1.25 Fr band

frequencies in the 0.25 Fr to 1.25 Fr band.

3. Maximum Attenuation at any frequency in the 0.25 Fr to 1.25 Fr band.

Consequently, when the first stage of the simulation is run, there are 3 different transfer functions found -- one for each of these worst-case conditions. The 2nd stage of simulation can use any one of these transfer functions.

The input to the first stage of simulation consists of all of the following:

1. Number of networks to be "built."
2. Number of devices.
3. Range of frequencies over which transfer function is to be retained.
4. Trunk length or total cable length.
5. Drop length or range of drop lengths.
6. Measured cable data.
7. The values of terminator elements at each end of the trunk.
8. The values of load elements at the non-trunk end of each drop.

When the trunk length is specified, the total cable length consists of this length and all of the drop lengths. When total cable length is specified, the trunk is diminished by the amount of the drop lengths. The trunk cable type can either be specified or else selected randomly from a group of cables.

Each drop is separately specified. Its location on the trunk is randomly selected within specified limits. For example, drop number 3 can be specified to be located anywhere along the trunk within a range of 0.8 to 0.83 of the trunk, with 0 being one end of the trunk and 1 being the other end. By specifying 0 and 1 for the limits for all drops, a BUS is constructed. By specifying 0.9999 and 1 as the limits a TREE is constructed.

The drop length can be specified or else its length can be selected randomly from 0 to a specified limit. The cable used for the drop can also be specified or else randomly selected from the group of cables.

Both trunk terminators are assumed identical. All drop loads are also assumed identical.

The transmitting device is applied to each drop (opposite the trunk end) and to each end of the trunk. If there are N drops, then there are N+2 locations at which the transmitting device is attached and (N+1)(N+2)/2 unique signal paths. A network having two drops and 6 unique transmission paths is illustrated in figure 2. If the locations for the transmit device are numbered 0 through 3, then the unique paths are:

0 ---> 1
0 ---> 2
0 ---> 3
1 ---> 2
1 ---> 3
2 ---> 3

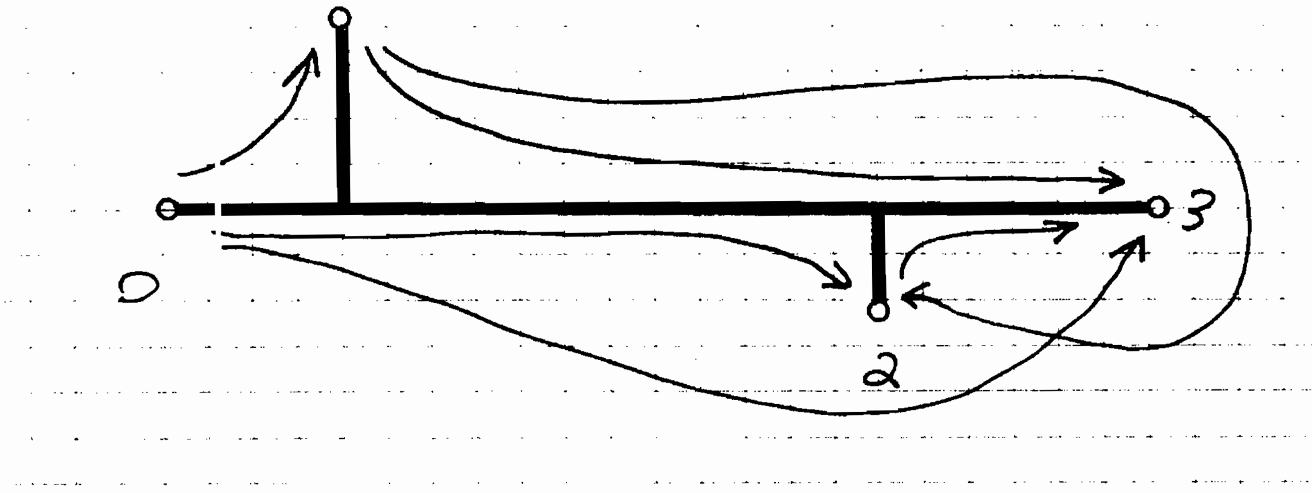


Figure 2

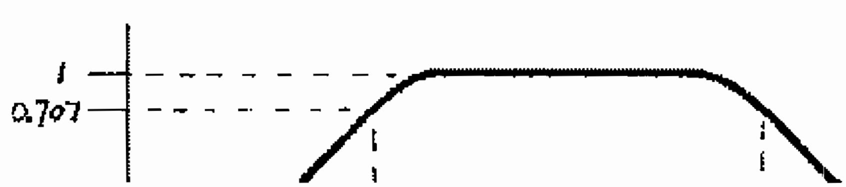
Unique Signal Paths For A Two-Drop Network

The transmitting device is assumed to be a current source. Consequently, the transfer functions are initially transimpedances. That is, they have a current input and voltage output. Each transimpedance is then normalized to the real part of the trunk terminator divided by two, so that it becomes a true transfer function. In other words, each transfer function is a comparison of an actual path to an ideal "path" consisting of just a pure resistance.

2.2 Second Stage Simulation

In the 2nd stage many random waveforms are generated. Each starts as a random bit stream. The random bit stream is then Manchester encoded. Following encoding, each Manchester waveform is trapezoidally shaped. The waveform is 0.9 millisecond in duration so that it contains approximately 28 bits.

The waveform slope is chosen to reduce the 3rd harmonic to zero. The waveform is sampled and FFTed to the frequency domain. Various filters are then applied. The first filter is a single-pole high-pass filter at 0.25 Fr. The second filter is a low-pass filter at 1.25 Fr. The purpose of these filters is to remove the small amount of signal energy that exists at the extremes of the Manchester power spectrum. A second purpose is to provide a gradual transition region between the band edges and a truncation filter which is applied at 4 kHz and 80 kHz (0.128 Fr and 2.56 Fr). The truncation filter truncates the spectrum so that everything below 4 kHz and above 80 kHz is set to zero, thereby reducing the amount of computation. Another reason that the spectrum is truncated is that cable data is only available from 1 kHz to 100 kHz. The combined single-pole and truncation filtering is illustrated in figure 3.



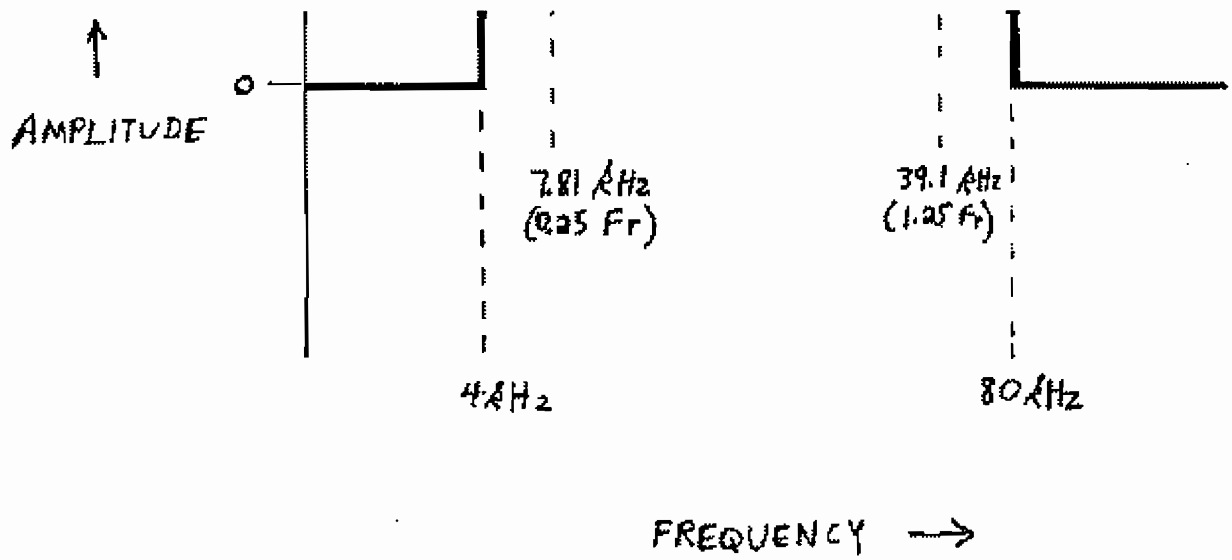


Figure 3

Single-Pole and Truncation Filters

3. How Many Networks?

As the number of networks used in a given simulation is increased, the program is able to find networks and network paths that are progressively worse. However, simulations using 100, 200, 500, and 1000 networks show that above 100 networks; the worst distortion is only a few percent greater than that found at 100 networks.

Similarly, in the 2nd stage of the simulation, very little is gained by using more than 100 waveforms in the eye diagram. Therefore, throughout nearly all of the simulations, 100 networks were used and 100 waveforms were generated for each worst-case transfer function.

4. Analysis Conditions

To keep the amount of data manageable, it is necessary to narrow the analyses choices. First of all, it is assumed that the total amount of cable is kept constant at 6000 feet. This is approximately the same as the 1900 meter upper limit specified for H1. Also, for networks using this much cable, we would probably require that the best cable be used. Therefore, only type A cable is included.

The bit rate is 31.25 kbits/second, which agrees with the present H1 spec.

Only BUS networks are used. This is based on numerous initial simulations which show that the BUS network invariably has greater distortion than the TREE.

Each terminator consist of a 100 ohm resistor in series with a 2 microfarad capacitor. Simulations were done for each of three drop loads (at end of each drop):

1. 1 picofarad capacitor (to simulate open circuit).

2. A 1000 pf capacitor.

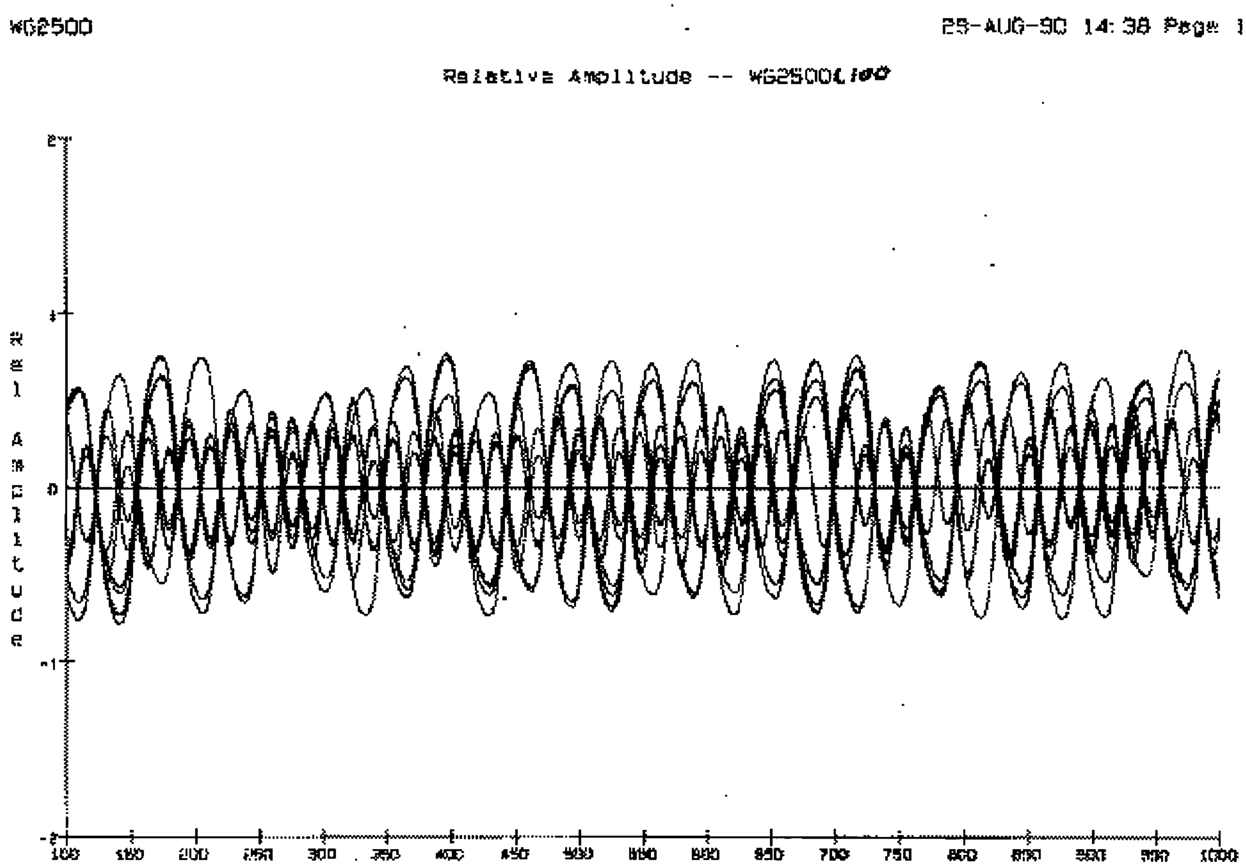
3. A 2500 pf capacitor.

The 1 pf load is used as a reference condition against which to compare other data. The 1000 pf and 2500 pf capacitances are thought to be representative of what will actually be used in H1 devices. The 2500 pf violates the existing H1 limit of 3000 ohm at 1.25 Fr. However, it is included for reference.

Fixed drop lengths of 1 ft., 100 ft., 200 ft., 300 ft., and 400 ft., are used. The 1 ft. drop is used as a reference condition. The number of drops is set to 10, 15, 20, and 32; depending on the length of the drops. (Long drop lengths require fewer drops to keep the total cable length within 6000 ft.)

5. Some Eye Diagrams

Some representative eye diagrams are shown in figures 4 through 8. All of these show only 10 waveforms instead of the 100 waveforms used in the general analysis. Other departures from the conditions stated in section 4 are also included to illustrate extremes.



Time (microsec)

Figure 4

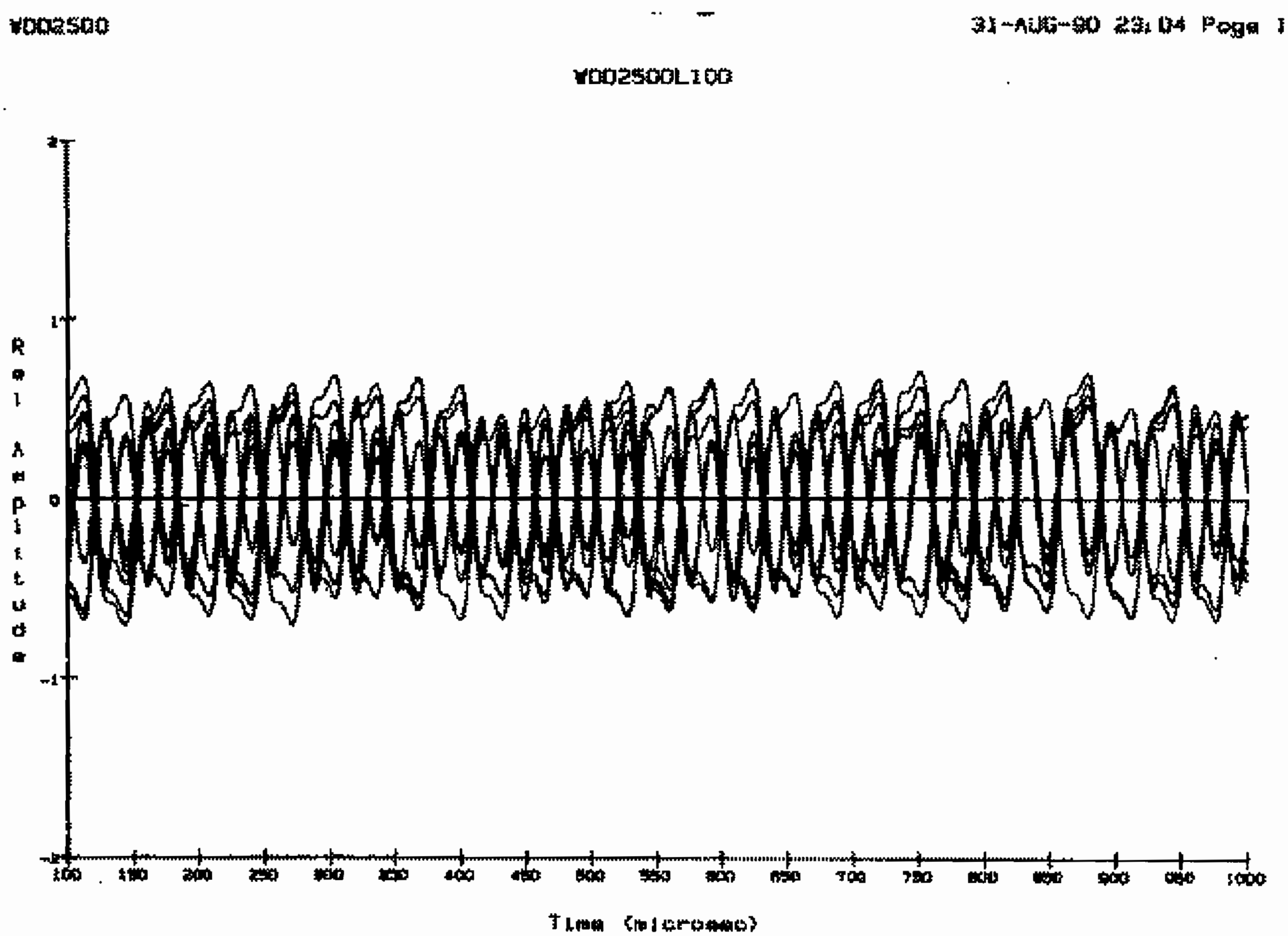


Figure 5

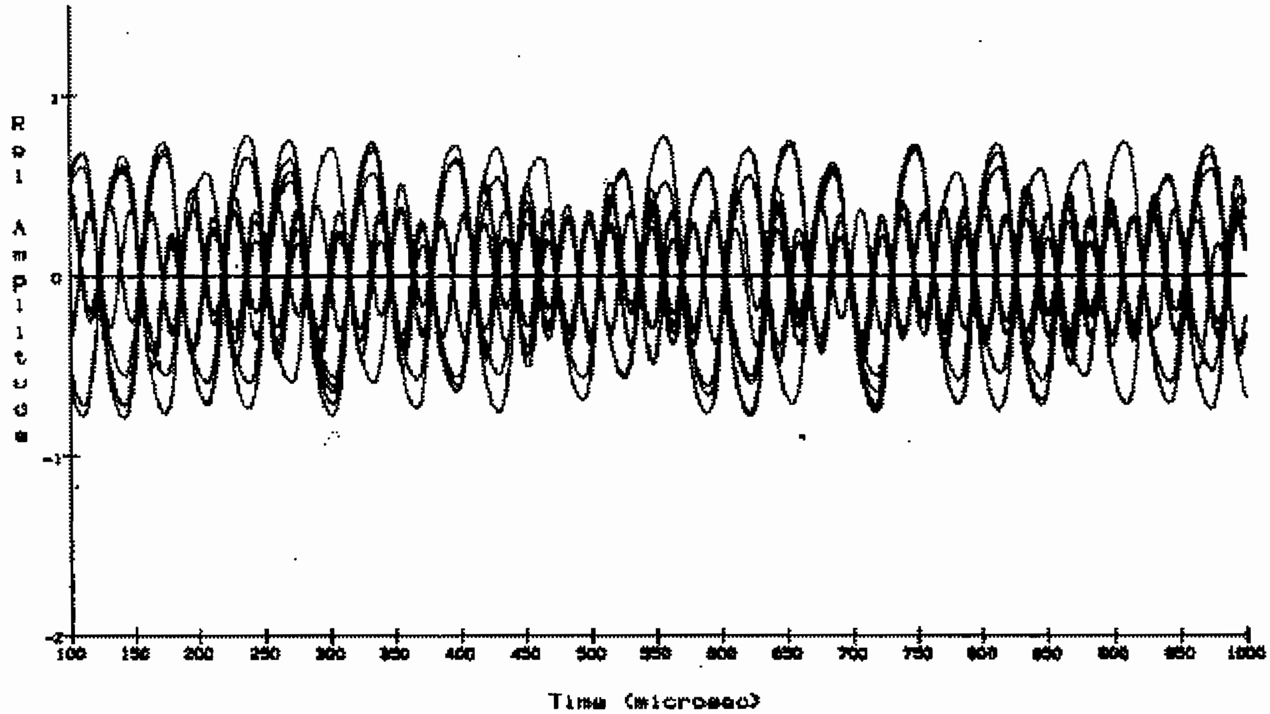
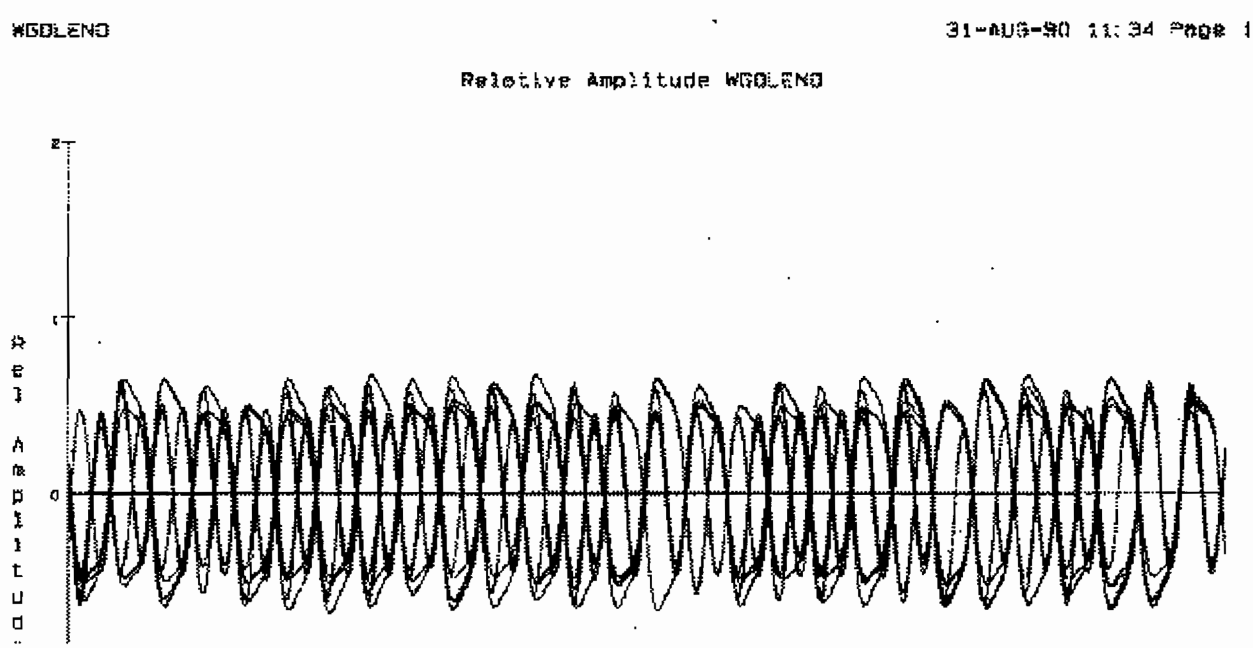


Figure 6

Figures 4 - 6 are all based on 32 devices, a drop load of 2500 pf, and drop length of 100 ft. Figure 4 used a worst-case gain (abbreviated WG) transfer function. Figures 5 and 6 used worst-case delay difference (WDD) and worst-case gain ratio (WGR) transfer functions, respectively.



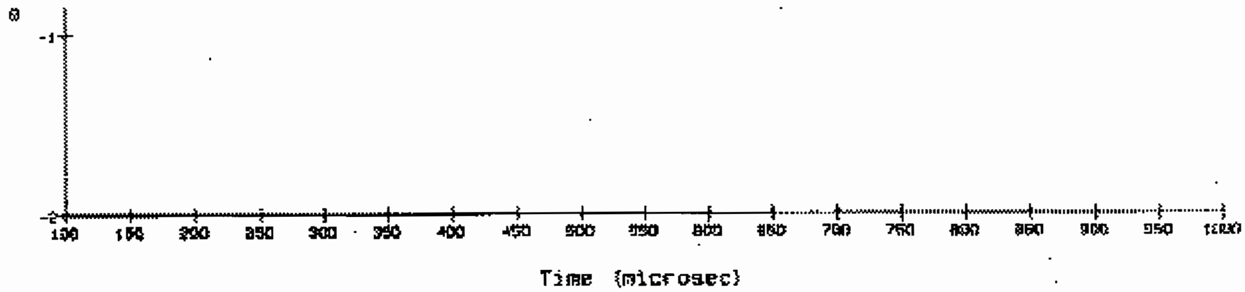
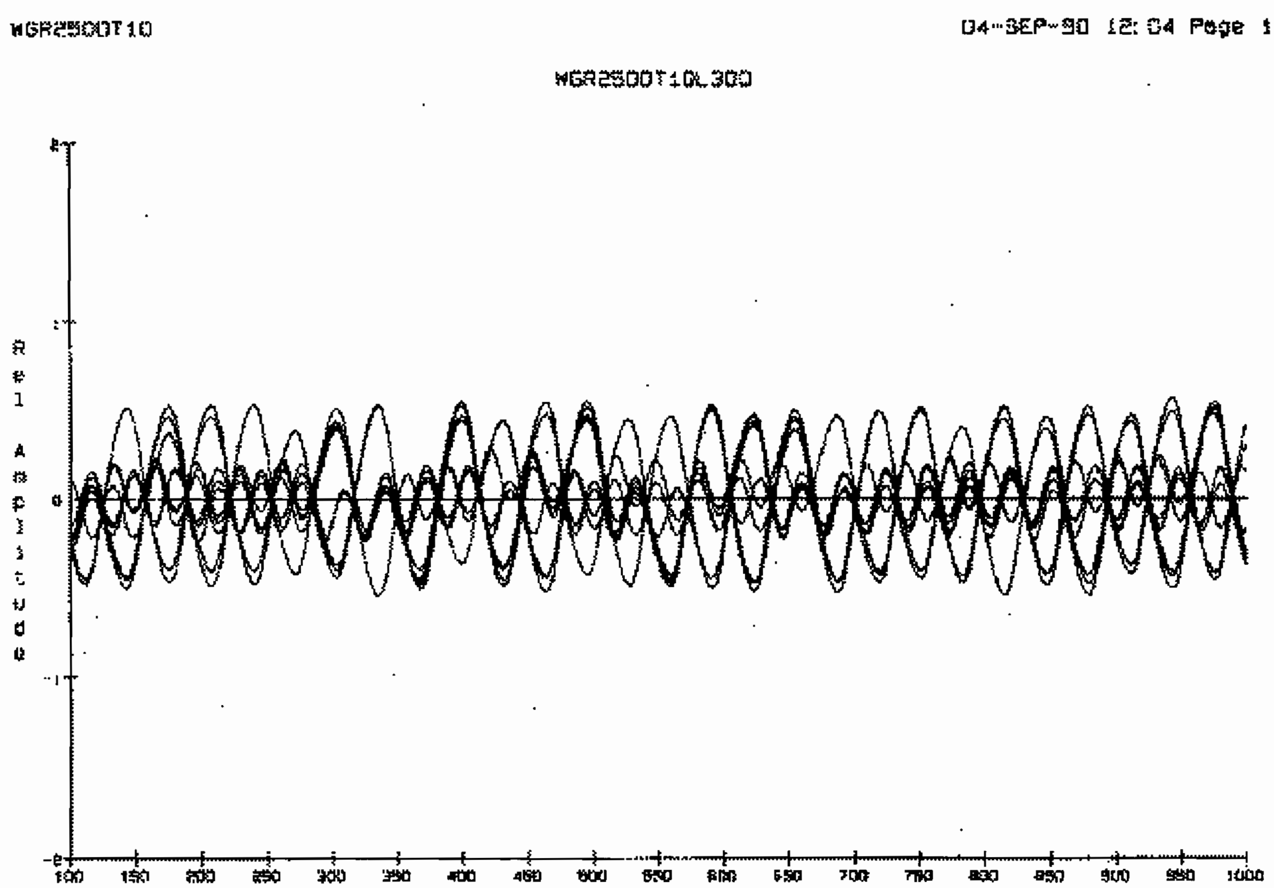


Figure 7

Figure 7 is a WG eye diagram that used 32 devices, a drop load of 1 pf, and drop length of 1 ft. This is a reference condition representing the best that can be done with essentially just the trunk cable alone. The received amplitude is typically 0.4 to 0.6 of the transmit (reference) amplitude throughout the diagram.

At the other extreme is figure 8, which is the WGR diagram for 32 devices, 2500 pf drop loads, and 300 ft drop lengths. The total cable for this particular simulation was increased to 10,000 ft. to accommodate the large drop lengths. The diagram shows complete eye closure at some points.



Time (microsec)

Figure 8

6. Results

The first stage simulations consider 3 different drop loads and 14 different drop length/field device number combinations; for a total of 4200 network constructions. From these, 126 worst-case paths are selected based on the 3 worst-case criteria given above. In the 2nd stage, 100 waveforms are passed through each of the 126 paths; for a total of 12,600 waveforms.

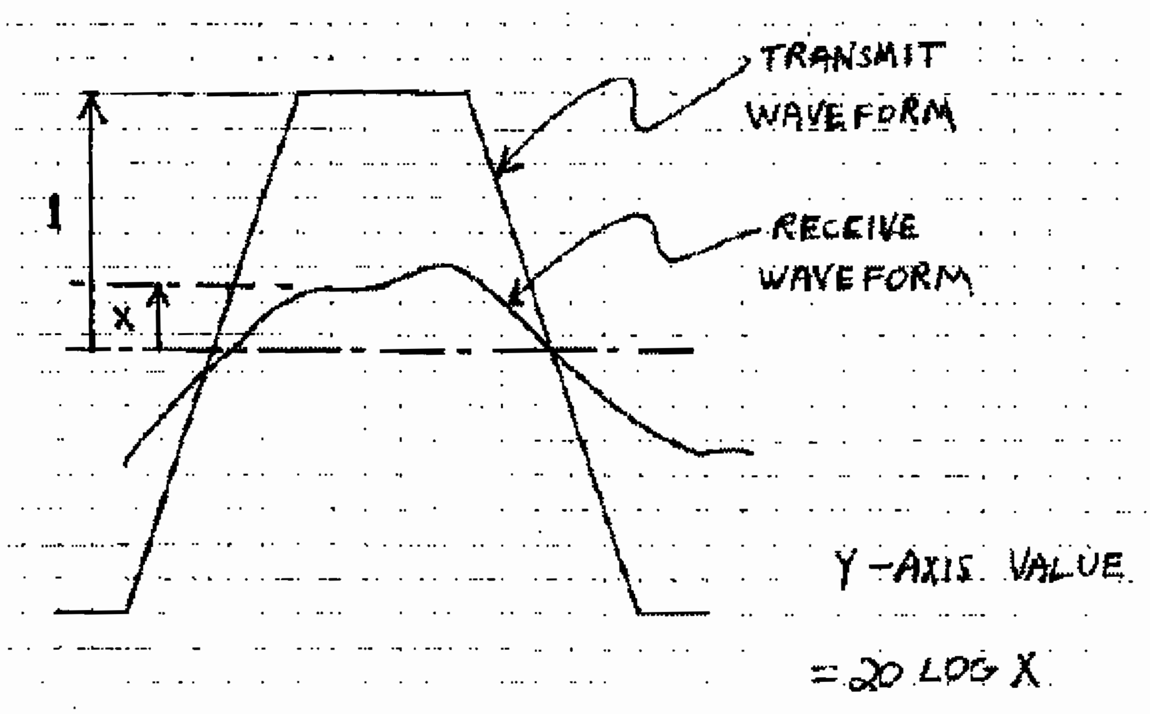


Figure 9

The data is presented in figures 10 through 19 in the form of minimum eye opening versus number of drops and drop length. The Y axis value is the minimum eye opening in dB below the transmitted signal. This is derived as shown in figure 9. Figures 10, 11, and 12 are WG (worst-case gain) curves for 1pf, 1000 pf, and 2500 pf drop loads, respectively. Figures 13, 14, and 15 are WDD (worst-case delay difference) curves for 1 pf, 1000 pf, and 2500 pf drop loads, respectively. Figures 16, 17, and 18 are WGR (worst-case gain ratio) curves for 1 pf, 1000 pf, and 2500 pf drop loads, respectively.

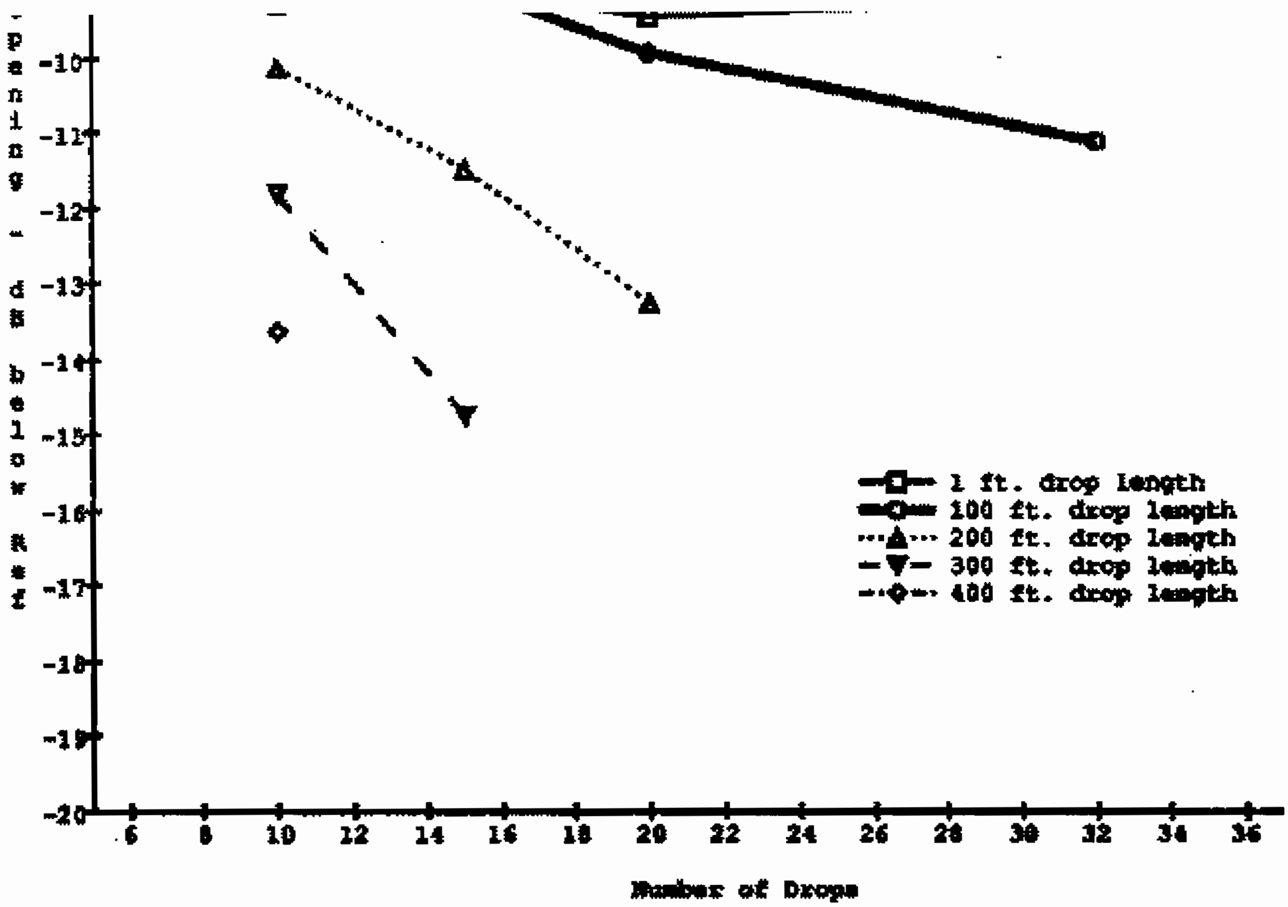
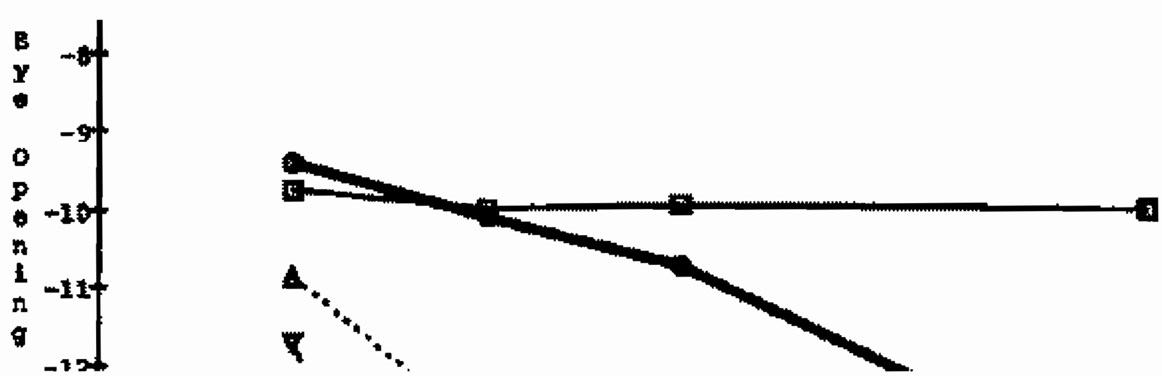


Figure 10

WG/C1 Eye Opening Vs # Drops

1 pf load, worst-case gain



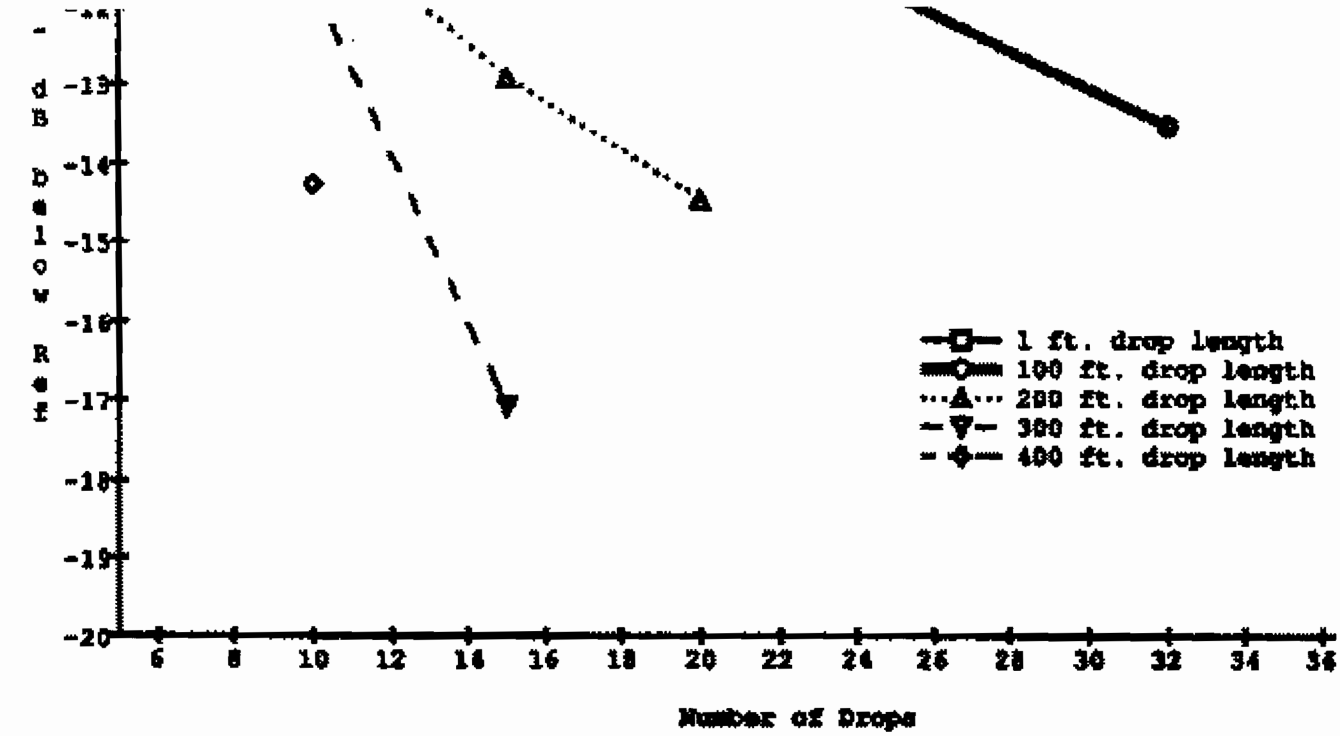
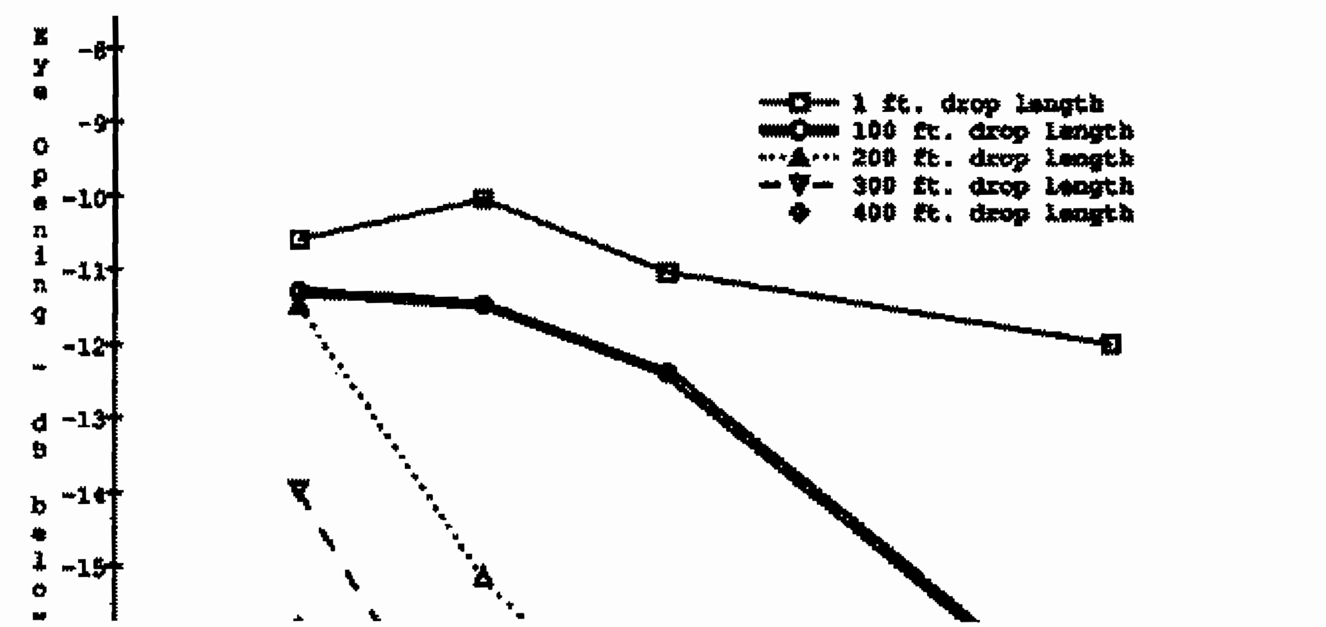


Figure 11

WG/C1000 Eye Opening Vs # Drops

1000 pf load, worst-case gain



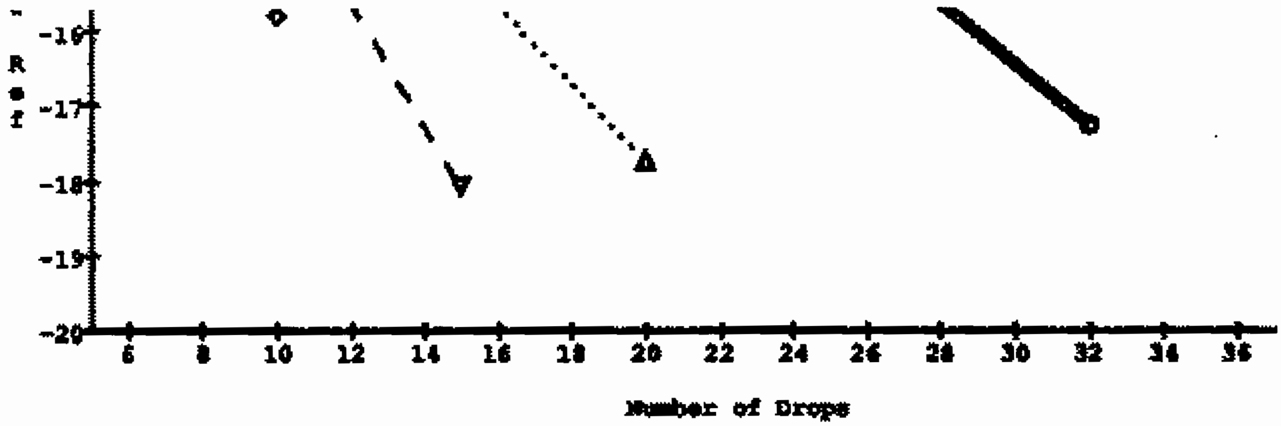
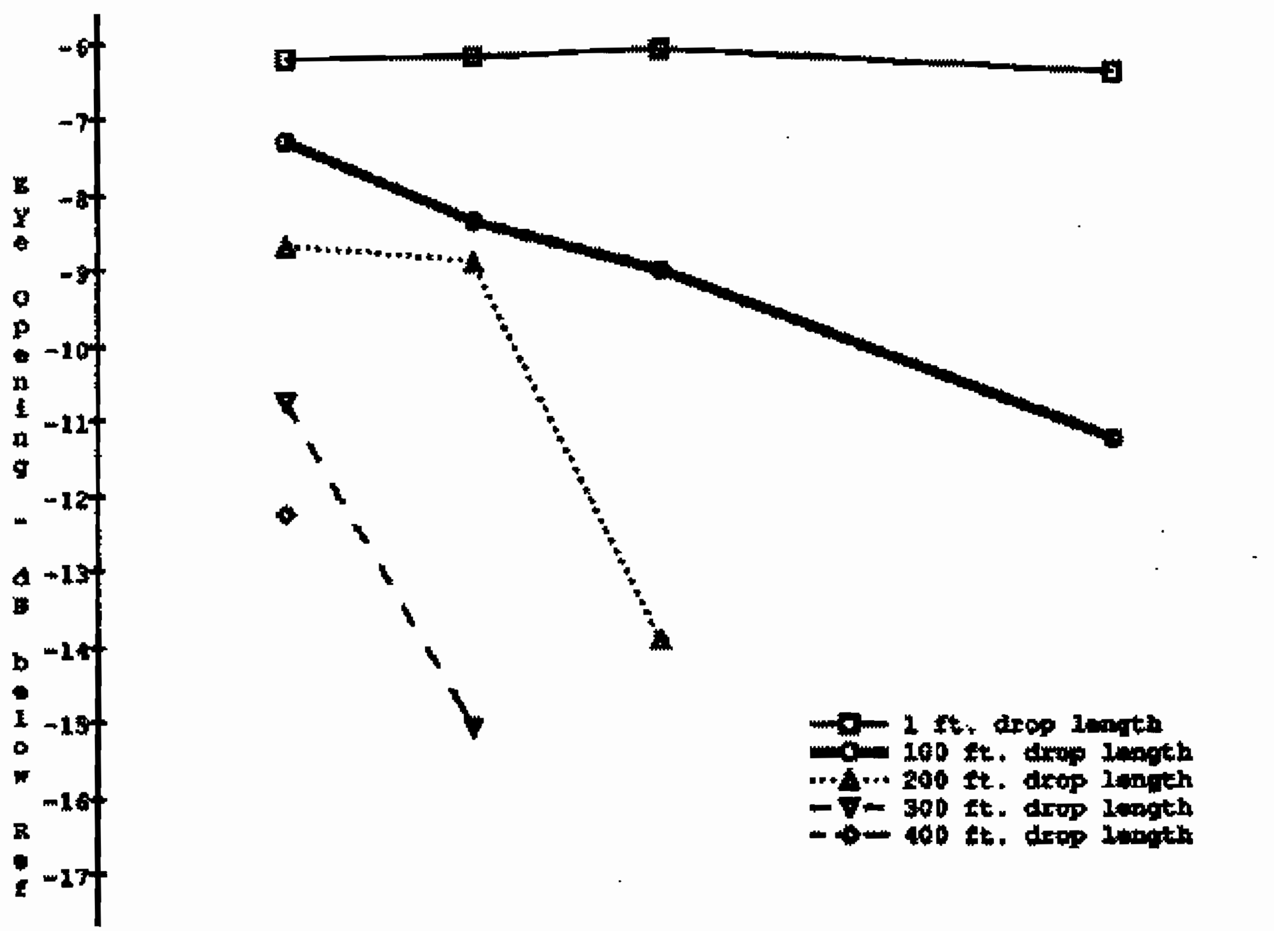


Figure 12

WG/C2500 Eye Opening Vs # Drops

2500 pf load, worst-case gain



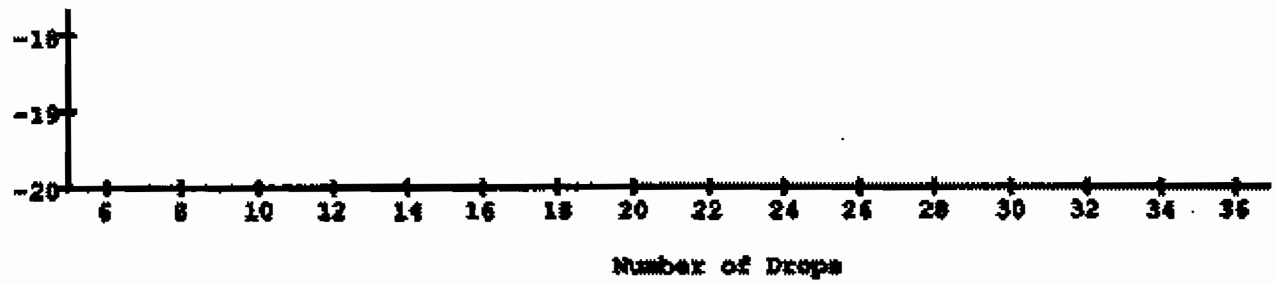
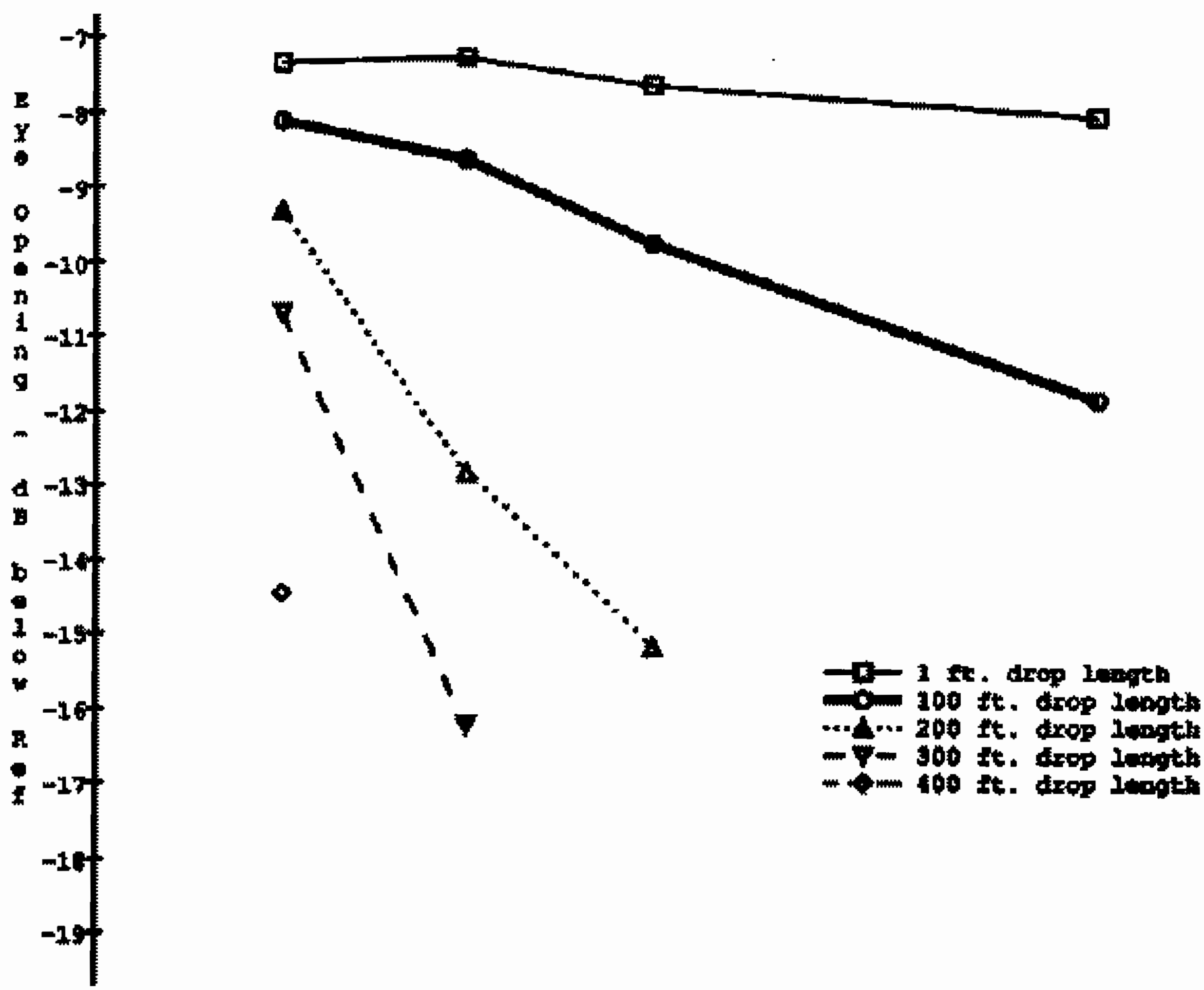


Figure 13

WDD/C1 Eye Opening Vs # Drops

1 pf load, worst-case delay difference



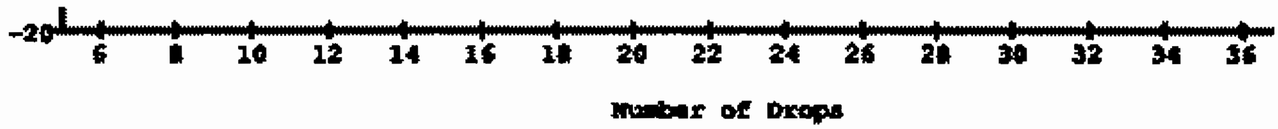


Figure 14

WDD/C1000 Eye Opening Vs # Drops

1000 pf load, worst-case delay difference

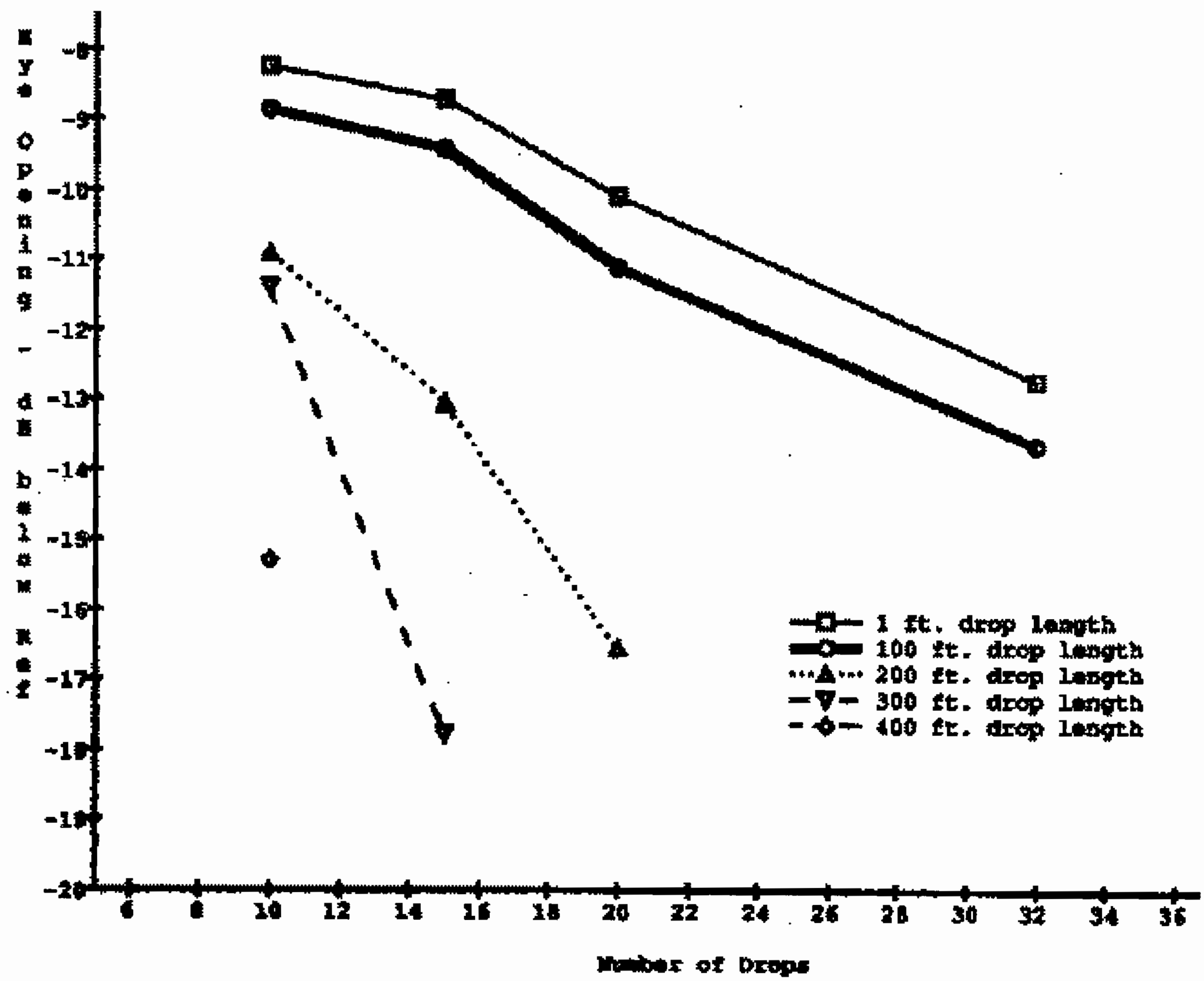


Figure 15

WDD/C2500 Eye Opening Vs # Drops

2500 pf load, worst-case delay difference

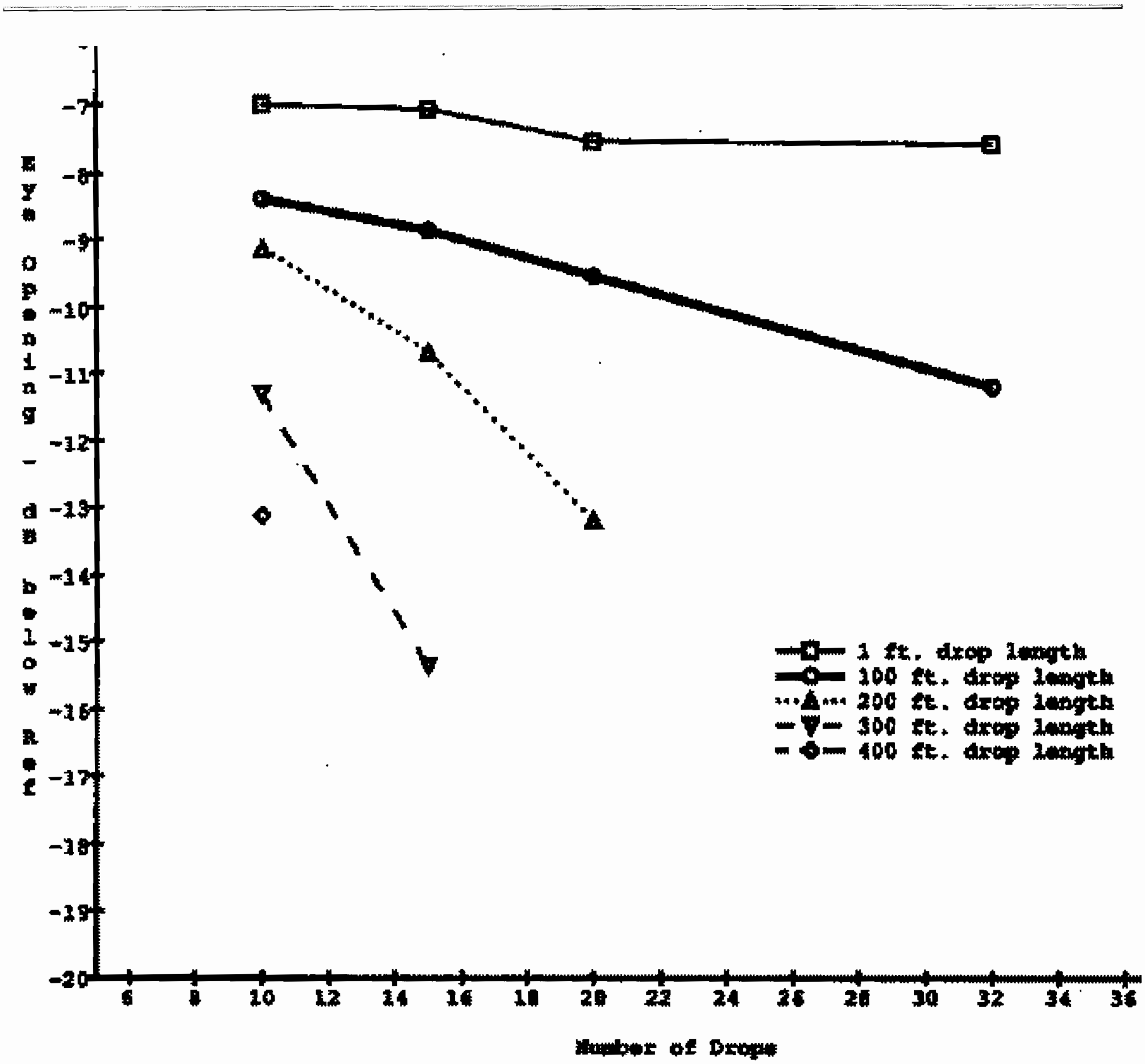


Figure 16

WGR/C1 Eye Opening Vs # Drops

1 pf load, worst-case gain ratio

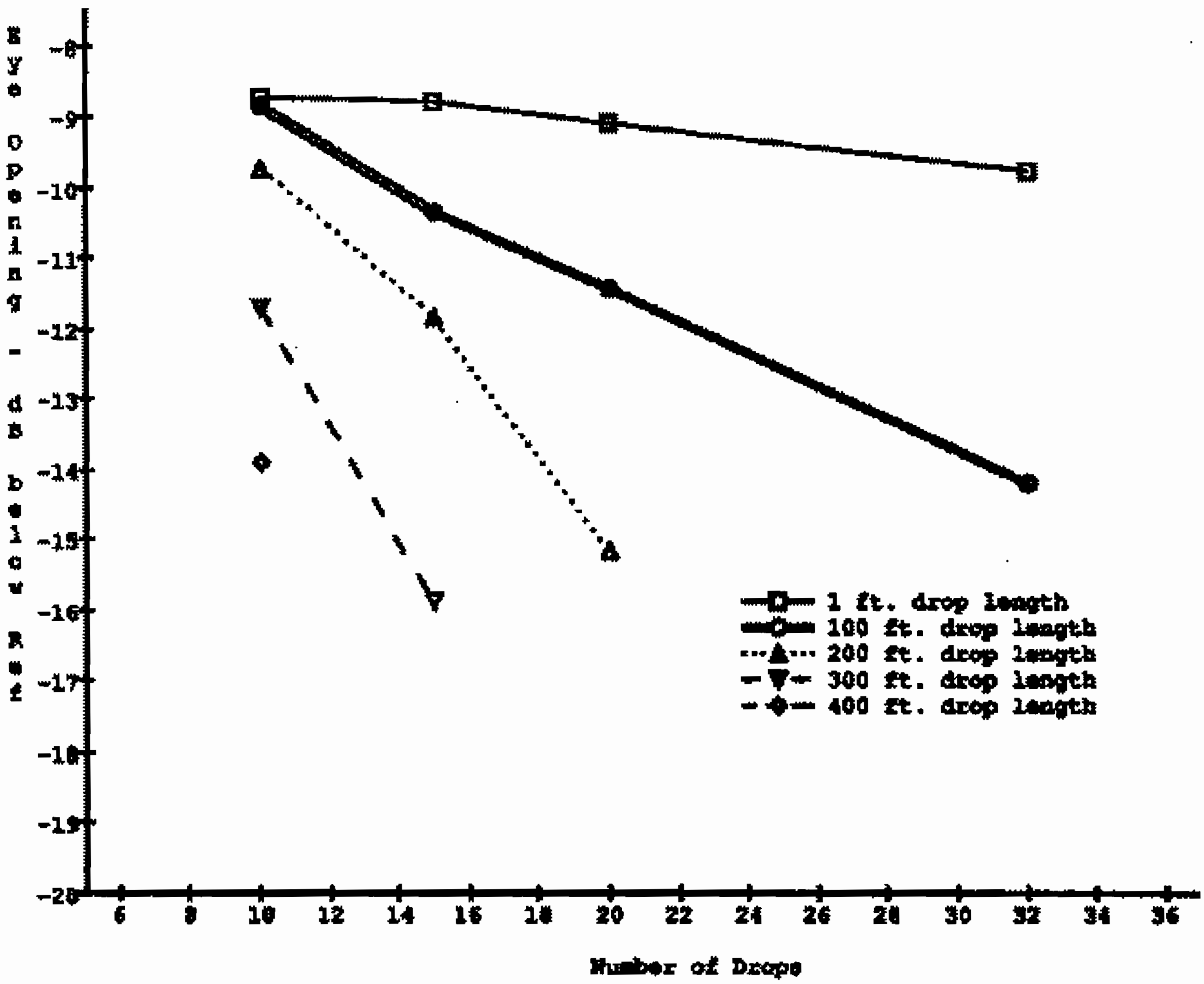


Figure 17

WGR/C1000 Eye Opening Vs # Drops

1000 pf load, worst-case gain ratio

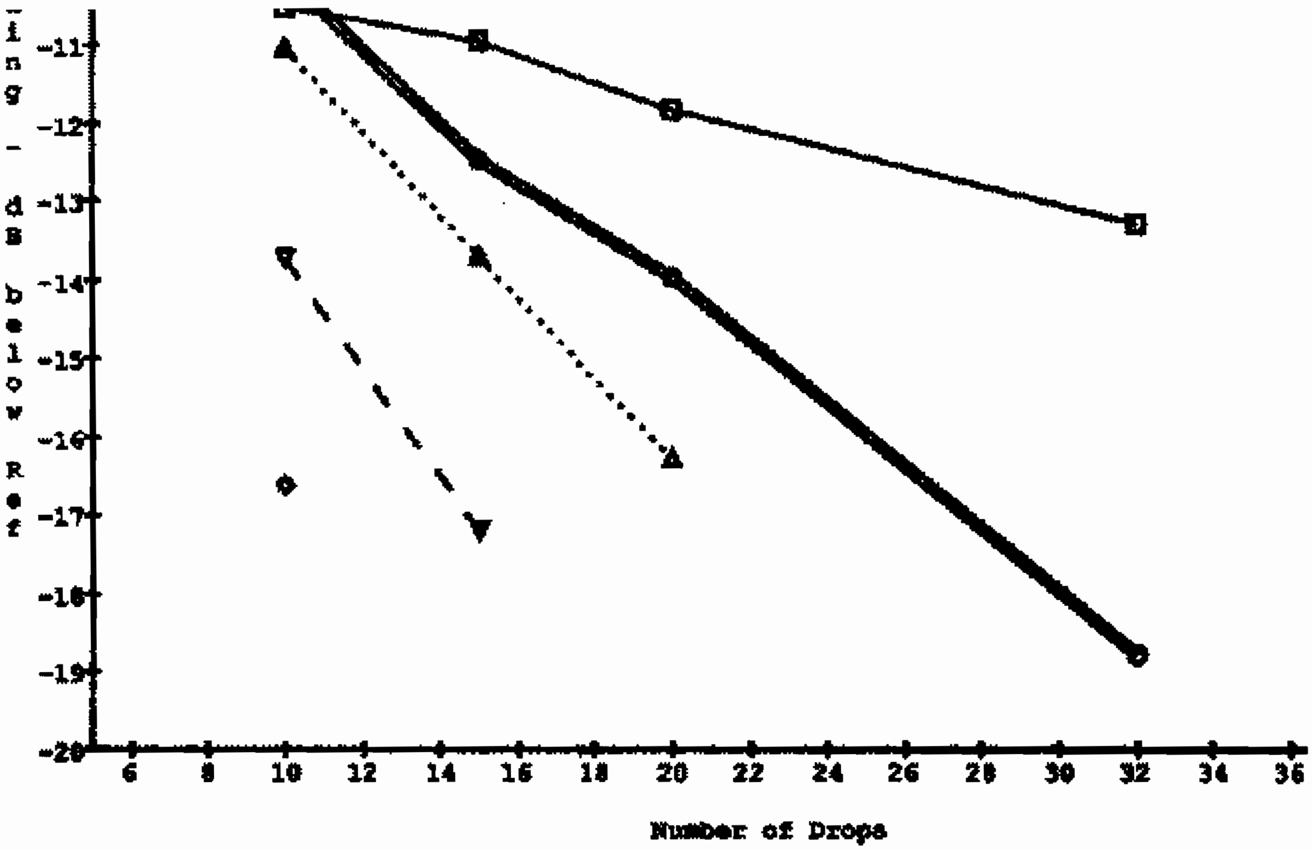


Figure 18

WGR/C2500 Eye Opening Vs # Drops

2500 pf load, worst-case gain ratio

For the situations simulated, the attenuation ranges from a low of about 6 dB to a high of 19 dB. Suppose that a 1000 pf load is considered the nominal situation. Then the WG curves (figure 11) have greater attenuation than either WDD (figure 14) or WGR (figure 17). Suppose we want to limit attenuation to 12 dB. Then from figure 11 the acceptable combinations of drop lengths and number of devices are

```
10 devices, 300 ft.
15 devices, 100 ft.
20 devices, 100 ft.
32 devices,   1 ft.
```

The WDD data predicts the same combinations. The WGR data predicts almost the same combinations, except that for 15 devices, 200 ft. drop lengths appear to be OK.

7. Comparison With Standard

Annex C of the current Standard has the following:

```
1 to 12 devices,    394 ft.
13 to 14 devices,   295 ft.
```

```
15 to 18 devices,   197 ft.
19 to 24 devices,    98 ft.
25 to 32 devices,     0 ft.
```

These numbers were derived assuming a 38.4 kbits/second bit rate and with no direct derivation of minimum eye opening. They are based on attenuation and delay distortion derived in simulations similar to those of the stage 1 simulations used here. The new data roughly follows that of Annex C, but is slightly more restrictive. This suggests that the Annex C conditions will produce eye openings of greater than 12 dB below reference.

The Standard currently specifies less than 10.5 dB attenuation between any two devices over the frequency range of 0.25 Fr to 1.25 Fr. As stated in the Standard, this attenuation is the value that would be measured using a sine wave generator. Therefore, it is not the same as minimum eye opening used in the simulations. However, the stage 1 part of the simulations generate worst-case transfer functions over this frequency range. Therefore, worst-case attenuation data is available for all of the network conditions simulated. The attenuation for various selected conditions is given in table Table 1 below.

TABLE 1

NUMBER DEVICES	LOAD (pf)	DROP LENGTH (ft.)	WORST-CASE CRITERION	FREQ OF MAX ATTEN (Hz)	ATTENUATION (dB)
10	1	1	wg	37829.7	5.18844
10	1	1	wdd	26013.8	1.26468
10	1	1	wgr	37829.7	2.10947
10	1000	300	wg	37829.7	6.61848
10	1000	300	wdd	28036.9	4.34874
10	1000	300	wgr	37829.7	6.22010
10	1000	400	wg	37829.7	8.10311
10	1000	400	wdd	32567.3	6.52790
10	1000	400	wgr	37829.7	8.10311
10	2500	300	wg	37829.7	7.45721
10	2500	300	wdd	28036.9	4.63118
10	2500	300	wgr	37829.7	6.99177
10	2500	400	wg	37829.7	9.03194
10	2500	400	wdd	32567.3	6.84938
10	2500	400	wgr	37829.7	8.96561
15	1000	100	wg	37829.7	5.31825
15	1000	100	wdd	28036.9	3.23399
15	1000	100	wgr	37829.7	4.66551
15	1000	200	wg	37829.7	6.69255
15	1000	200	wdd	30217.3	5.07992
15	1000	200	wgr	37829.7	6.22394
15	1000	300	wg	37829.7	8.99871
15	1000	300	wdd	32567.3	7.17377
15	1000	300	wgr	37829.7	8.75540
15	2500	100	wg	37829.7	6.18720
15	2500	100	wdd	26013.8	3.72105
15	2500	100	wgr	37829.7	5.86918
15	2500	200	wg	37829.7	7.40146
15	2500	200	wdd	28036.9	5.59357
15	2500	200	wgr	37829.7	7.36236

15	2500	300	wg	37829.7	9.89252
15	2500	300	wdd	30217.3	7.63898
15	2500	300	wgr	37829.7	9.81237
20	1000	100	wg	37829.7	5.90881
20	1000	100	wdd	28036.9	3.84571
20	1000	100	wgr	37829.7	5.28748
20	1000	200	wg	37829.7	8.02780
20	1000	200	wdd	32567.3	6.40343
20	1000	200	wgr	37829.7	7.89213
20	2500	100	wg	37829.7	7.24218
20	2500	100	wdd	26013.8	4.81659
20	2500	100	wgr	37829.7	6.80074
20	2500	200	wg	37829.7	9.29627
20	2500	200	wdd	28036.9	7.37015
20	2500	200	wgr	37829.7	8.79271
32	1000	100	wg	37829.7	7.24991
32	1000	100	wdd	28036.9	5.02209
32	1000	100	wgr	37829.7	7.17889
32	2500	100	wg	37829.7	9.53652
32	2500	100	wdd	26013.8	6.58590
32	2500	100	wgr	37829.7	9.39462

It is seen from the table that the attenuation is never as great as 10.5 dB. Therefore, the existing network configuration "rule" is satisfied by every network simulated, even though some of these same networks produce eye openings that are unacceptably small.

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